An automatic EEG-assisted retrospective motion correction for fMRI (aE-REMCOR)

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Purpose: Head motion during functional magnetic resonance imaging (fMRI) impairs the quality of the data. Electroencephalography (EEG) concurrently acquired with fMRI provides high temporal resolution information about brain activity as well as subject head movement. Recently an EEG-assisted retrospective motion correction (E-REMCOR) method that utilizes EEG data to correct for head movements in fMRI on a slice-by-slice basis was developed. [1] While E-REMCOR was shown to be capable of substantially removing head movements in the fMRI dataset, it involves experienced personnel to identify the motion-related independent components (ICs) in the EEG data. To enhance the usability of E-REMCOR, especially for the rapidly growing interest in concurrent EEG and fMRI measurements, we developed an automatic way to preprocess the EEG data, analyze IC properties, and identify the motion ICs.

Methods: E-REMCOR consists of independent component analysis (ICA) on the preprocessed EEG data (after MRI artifact removal), the identification of independent components corresponding to the head motions, and the utilization of the EEG-based motion ICs as regressors to correct the fMRI dataset. The automation of E-REMCOR (aE-REMCOR) follows the original procedures, [1] except that the correction of motion induced by the cardiac cycle is handled by AFNI 3dtfitter instead of 3dretroicor, and a second ICA is performed for the refinement of the selected motion ICs. The automatic preprocessing and analyses of the EEG data and identification of motion ICs are carried out in Matlab and EEGLAB. The identification of motion ICs is accomplished by analyzing and categorizing the special features of the motion artifacts imposed on the mean power spectrum and the topographical map of the ICs, as well as on the contribution of the ICs to the EEG signals (Fig.1). To understand the physical origin of the ICs, the mean power spectra over windows of 512 data points and 256 data points overlapped are calculated (Fig.1c,g). Spectral peak properties are analyzed in different frequency ranges: rapid head movement (RM: 0.5–4.5 Hz), motion caused by cardioballistic artifact (CB: 2–7 Hz), eye blink/saccade (0.5–3 Hz) and neuronal activity (8–12 Hz). A motion IC candidate is selected according to certain spectrum peak and convexity features in the RM and CB frequency ranges. In particular, for the ICs corresponding to the cardioballistic artifact, obvious peaks can be found in the CB frequency range. The spatial projection of the IC contribution to the EEG channels forms topographical map (Fig.1d,h). The topographic maps corresponding to the rapid head movement (Fig.1d) exhibit an opposite polarity, [1] while those corresponding to the cardioballistic artifact (Fig.1h) exhibit single polarity or opposite polarities. [2] During the automation process, the polarity regions of any kind of the motion IC are assumed to be positioned on the edge of the map, since it is the farthest area from the pivot point of the head and is affected most by the head movement. The polarity region of the topographical map is defined by certain threshold values. The position, area ratio, and arc area ratio of the polarity regions are analyzed to identify the motion IC. When there is rapid head movement, prominent spikes with duration no less than tens of milliseconds are found in the time courses of the motion IC (Fig.1a) and the EEG signals recorded by the edge electrodes. Removing the contribution of the motion IC from the EEG signal reduces the spikes significantly (Fig.1b). For the IC associated to the motion induced by the cardioballistic artifact, a distinct time period of the heart pulse can be observed in the time course (Fig.1e). The signal contribution of this IC is more or less constant over time (Fig. 1f). Thus the motion IC caused by cardioballistic artifacts can be signified by a smaller average at the peak positions of the EEG signal after the removal of that particular IC. Finally, eye blink/saccadic ICs categorized by their spectra and topographical maps are removed from the motion IC category (algorithm is not described here). Temporal signal-to-noise ratio (TSNR) is calculated after the volume registration using AFNI 3dvolreg. [1,3] The TSNR difference (ΔTSNR) between the fMRI datasets with and without automatic E-REMCOR is compared.

Automatically selected motion ICs

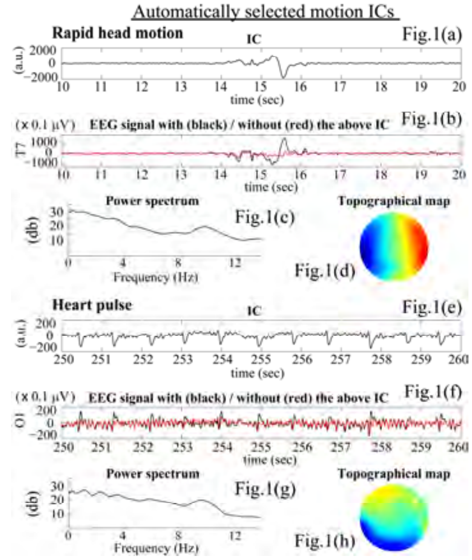
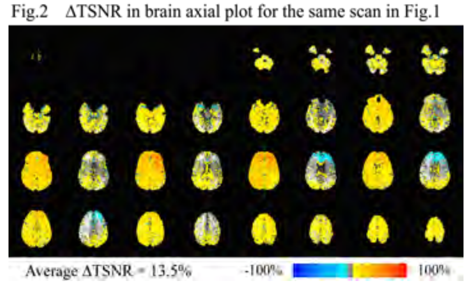
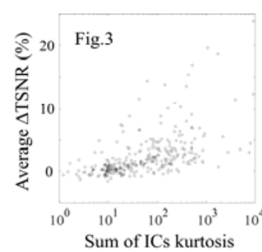
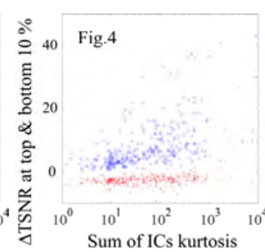


Fig.2 ΔTSNR in brain axial plot for the same scan in Fig.1







Results: The aE-REMCOR was applied to 305 fMRI scans acquired at 3 Tesla. Each scan lasts for 8 min 46 sec. The typically identified motion ICs for a subject with rapid head movement are shown in Fig.1. Fig 2 shows the corresponding ΔTSNR. Larger ΔTSNR (>50%) are found in the voxels on the brain edge region, as these areas are affected most by rapid head movement. Since a large kurtosis is usually observed in the ICs corresponding to the rapid head movement, we used the sum of the kurtosis of the selected ICs to estimate the severity of the head motion. The average ΔTSNR over the brain for each scan is plotted against the kurtosis sum of the selected ICs in Fig.3. Fig.4 shows the value of ΔTSNR at the upper (blue) and lower (red) 10th percentile. Depending on the subject's motion, a higher ΔTSNR can usually be achieved with more significant motions (or a larger kurtosis sum). The average ΔTSNR over the brain goes up to 24%, and the largest 10 percent of the ΔTSNR reaches over 43%. In most cases when the subjects have no significant motion, the average TSNR may increase slightly or decrease by less than 1%, implying that the correction of motion induced by the cardiac cycle using 3dtfitter is comparable to that using 3dretroicor.

Summary: An automatic EEG-assisted retrospective motion correction (aE-REMCOR) method to correct motion in the fMRI data was developed. The automation is shown to be capable of substantially removing head motions in fMRI images. Depending on the subject's motion, the average change of the TSNR over the brain with aE-REMCOR goes up to 24%, and the largest 10 percent of the TSNR improvement reaches over 43%. This works is supported by DOD award W81XWH-12-1-0607.

References: 1. Zotev V, Yuan H, Phillips R., et al. EEG-assisted retrospective motion correction for fMRI: E-REMCOR. NeuroImage. 2012;63:698-712. 2. McMenamin B, Shackman A, Maxwell J, et al. Validation of ICA-based myogenic artifact correct for scalp and source-localized EEG. NeuroImage. 2010;49:2416-2432. 3. Bodurka J, Ye F, Petridou N, et al. Mapping the MRI voxel volume in which thermal noise matches physiological noise- implications for fMRI. NeuroImage. 2007;34:542-549.